Government Reference Link Models: ORCA

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Mathematical Link Models

- Government will provide mathematical models for
  - Uplink (slant) paths
  - Downlink (slant) paths
  - Horizontal paths
- Models can be useful tool for system design

References

L. C. Andrews and R. L. Phillips, *Laser Beam Propagation Through Random Media*, 2nd ed., SPIE Press (2005).

L. C. Andrews, R. L. Phillips, and C. Y. Hopen, *Laser Beam Scintillation with Applications*, SPIE Press (2001).

L. C. Andrews, *A Field Guide to Atmospheric Optics*, SPIE Press (2004).

Optical Atmospheric Propagation Effects

- **Absorption & Scattering (extinction)**
  - Attenuation of optical wave
  - Reduces received power
  - Limits optical channel availability in the presence of fog or clouds

- **Fluctuations in Index of Refraction**
  - Small temperature fluctuations cause refractive-index fluctuations known as *optical turbulence*
  - Cause intensity and phase fluctuations on propagating beam

- **Atmospheric Links**
  - Extended path turbulence between Transmitter and Receiver (Tx & Rx)
    - Uplink/downlink to/from aircraft
    - Aircraft to aircraft
  - Aero-optic effect around aircraft, especially with external dome
    - Modeled as thin turbulent layer (phase screen) near Tx/Rx

- Propagation Effects on Beam
  - Larger beam spot size at receiver
    - Leads to additional power loss in signal
  - Beam wander
    - Caused by turbulent eddies near Tx
    - Contributes to long-term spot size
    - Can contribute to scintillation
  - Scintillation (intensity fluctuations)
    - Reduces signal-to-noise ratio (SNR)
    - Leads to signal fades
  - Phase fluctuations
    - Angle-of-arrival fluctuations (causes beam jitter on detector)
    - Reduces spatial coherence of beam (determines speckle size at Rx)
    - Limits heterodyne efficiency in coherent detection
    - Limits "effective" Rx aperture size for improved SNR to size of r_0

r_0 = Fried's parameter

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Mitigation of Atmospheric Effects on Optical Communication Link

- **Transmitter System Architecture**
  - *Increase transmitted power*
    - Improve SNR at Rx
  - *Multiple beams*
    - Sufficiently separated to ensure statistical independence at Rx
    - Produces aperture averaging of scintillation (similar to receiver array)
  - *Multi-mode beams*
  - *Partially coherent beams*
  - *Multiple frequency regimes*
    - RF and optical
  - *Adaptive optics*
    - Corrects phase distortions caused by optical turbulence

- **Receiver System Architecture**
  - *Incoherent (direct) detection*
    - intensity modulation
    - large aperture receiver (improve reliability)
    - array receivers (improve reliability)
  - *Coherent (heterodyne) detection*
    - intensity and phase modulation
    - large aperture receiver
    - array receivers

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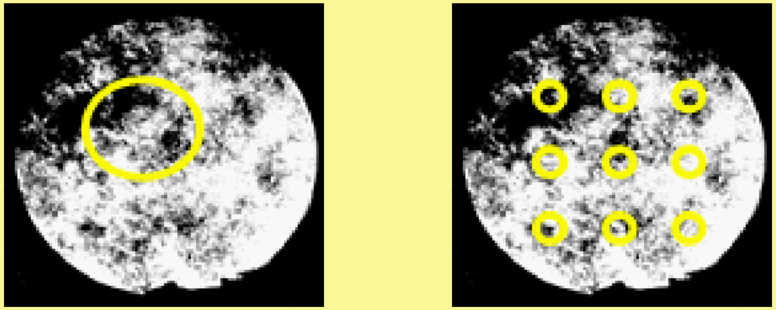
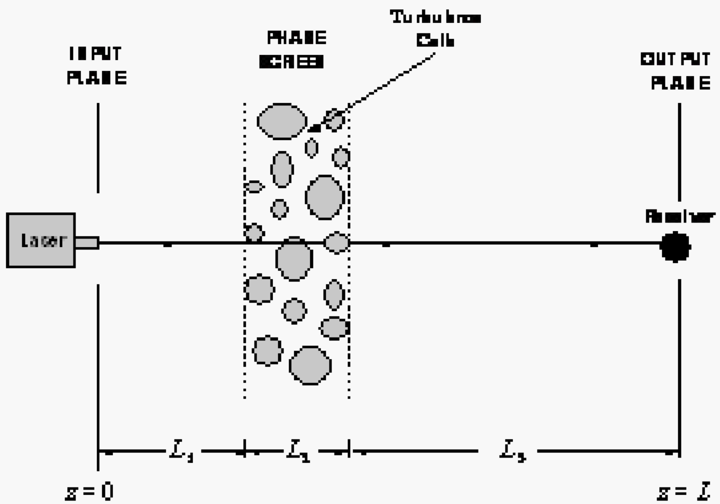
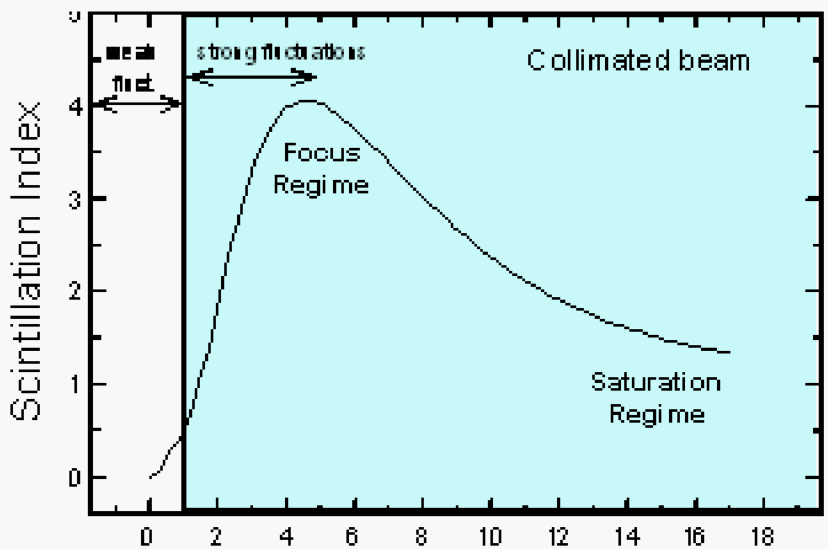
Intensity cross-section of beam after propagating thru extended turbulence. Dark patches denote a signal fade and yellow circle(s) depict (*a*) a large Rx aperture or (*b*) an array of small Rx apertures.

(*a*) (*b*)

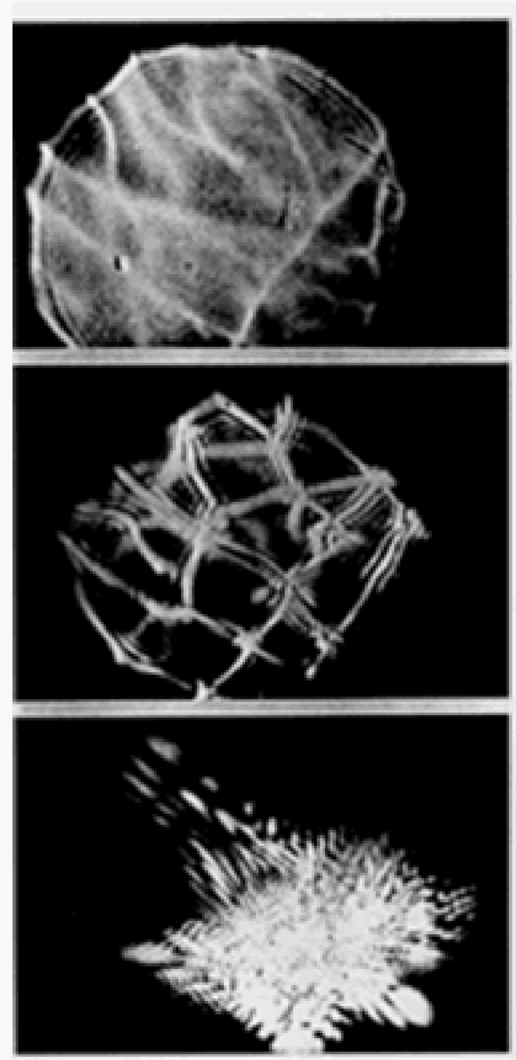


Intensity Fluctuations





$$\sigma_R = (1.23\, C_n^{\,2} k^{7/6} L^{11/6})^{1/2}$$



Emerging From Phase Screen

Focusing Regime

Saturation Regime

Figure Intensity profile of beam after passing through phase screen, immediately beyond (bottom), further beyond (middle), and far beyond (top) .

Mathematical Formulas

Propagation Paths

- *Uplink* (slant) path from ground to aircraft
- *Downlink* (slant) path from aircraft to ground
- *Horizontal* path between two aircraft

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Atmospheric Models

Kolmogorov Spectrum:

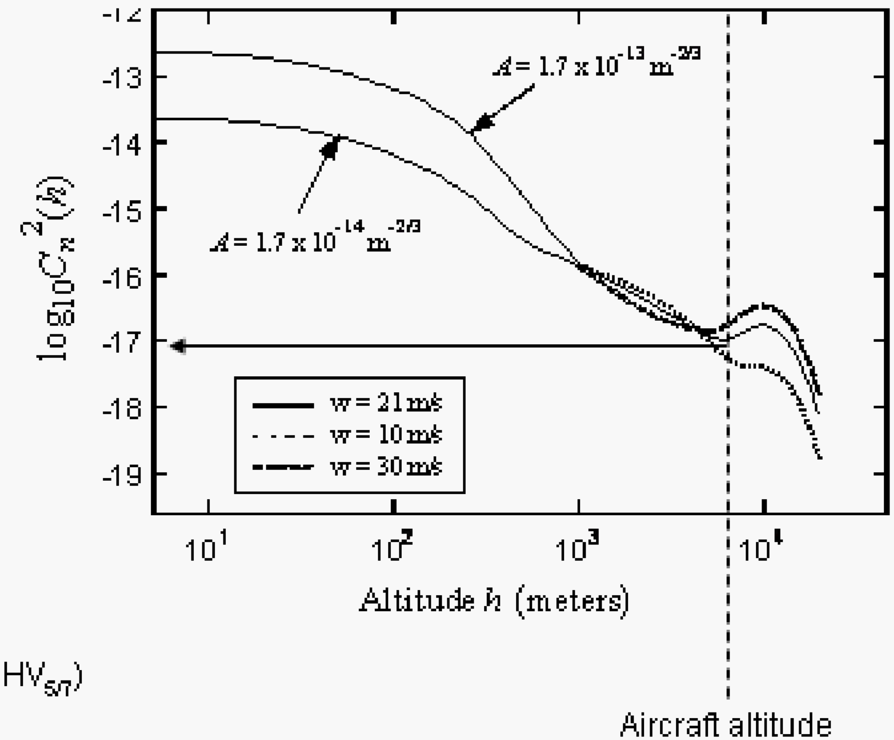
$$\Phi_n(\kappa, h) = 0.033 C_n^2(h) \kappa^{-11/3}$$

Hufnagle-Valley (HV):

$$\begin{cases} C_n^2(h) = 0.00594\left(\dfrac{w}{27}\right)^2 \left(10^{-5} h\right)^{10} \exp\left(-\dfrac{h}{1000}\right) \\ \qquad + 2.7\times 10^{-16} \exp\left(-\dfrac{h}{1500}\right) + A \exp\left(-\dfrac{h}{100}\right) \end{cases}$$

where

- h = altitude
- w = upper atmospheric pseudo-wind speed (= 21 m/s for $HV_{5/7}$)
- $A = C_n^2$ near ground level (= 1.7 × 10^{-14} $m^{-2/3}$ for $HV_{5/7}$)



CONCLUDING REMARKS

- **Scintillation index** (variance/mean^2) may be worse at weaker C_n^2
- **Aperture averaging** can reduce signal fluctuations
- **Speckle size** at long ranges through weak C_n^2 values may be too large for single aperture averaging
- **Array of small receivers** (properly separated) can reduce scintillation index more than single large aperture
- **Multiple beams** can reduce scintillation like an array of receivers

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